GLAST LAT TECHNICAL NOTE	Document # **LAT-TD-00037-1**	Date 5 Dec 2000
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Document Title
LAT Radiator Conceptual Design

1. Abstract

The GLAST Large Area Telescope (LAT) Radiators consist of two flat sandwich panels which extend down opposing sides of the spacecraft, below the bottom of the LAT Grid support structure. The radiators are mounted off the Grid, as well as being supported by the spacecraft. Expected relative motions between the LAT and spacecraft of up to 2 mm drive the design of these supports to be compliant. Analysis shows that a two-point support system for each radiator is adequate to handle the expected launch accelerations, and that the radiator panels can be stiffened to accommodate this support method, while maintaining a natural frequency of the system above the 70 Hz minimum target. A design concept for this solution is proposed, which can be used for placing and sizing the spacecraft supports as well as the Grid mounts.

2. Definitions

CTE	Coefficient of thermal expansion
f_1	First-mode natural frequency
IRD	Interface Requirements Document, between spacecraft and LAT
g	Acceleration due to gravity ($g = 9.81$ m/sec^2)
GEVS	Goddard Environmental Verification Specification
Hz	Hertz (cycles/second)
LAT	Large Area Telescope
lbf	Pound
N	Newton (kg-m/sec^2)
VCHP	Variable-conductance heat pipes

3. LAT Radiator Conceptual Design

3.1 Radiator Structural Design

3.1.1 Layout

The Large Area Telescope (LAT) Radiators are hung off the bottom edges of two opposing sides of the LAT Grid support structure, as well as being supported off the spacecraft. Figure 1 shows a conceptual layout of the LAT with its radiators. There are two reasons for this placement.

First, the Radiators are large, to adequately radiate the 650 watts of heat generated by the LAT, while keeping the LAT within a tight temperature range. For redundancy, and to allow for more operational flexibility, the active area is split between two radiators, mounted on opposite sides of the spacecraft. Second, the surface area of the LAT instrument is relatively small, and cannot be blocked by the radiators. This forces the radiators to be positioned below the active volume of the LAT and, because they are so large, requires that the spacecraft provide support for them.

3.1.2 Design

Structurally, the radiators are relatively straightforward. They are built on a skeleton frame consisting of aluminum heat pipes and close-out frames, in-filled with a honeycomb core, and sealed with aluminum facesheets. Aluminum was the logical material choice for the remainder of the radiators because we are using aluminum heat pipes. Using a single material eliminates the thermal stresses that might arise from different coefficients of thermal expansion (CTE).

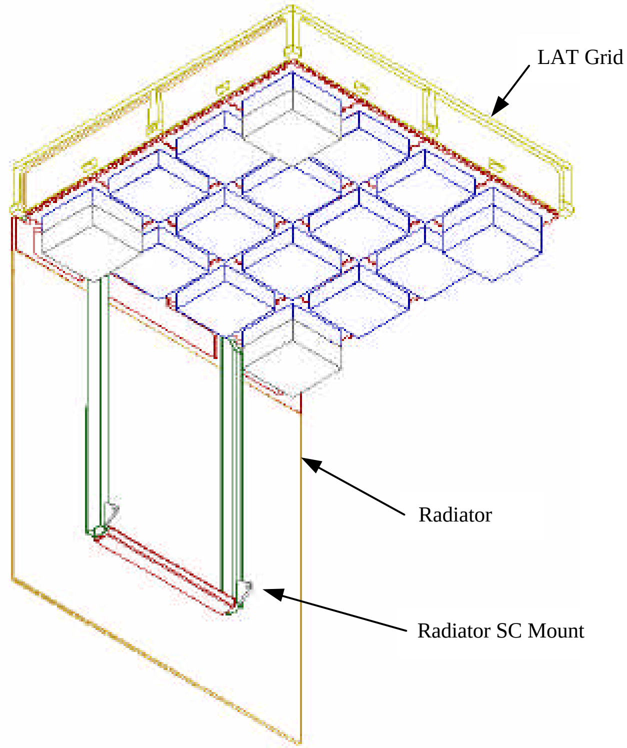

Figure 1: Underside of LAT and Radiators

Variable-conductance heat pipes (VCHP) extend out the top of the radiators, bend 90 degrees, and run parallel to the bottom edge of the Grid. Thermally, these VCHP's mount to the Grid, and are bonded to neighboring heat pipes on the Grid. Structurally, the top edge of the radiator is made from an aluminum plate, which bolts to the Grid. This plate transmits loads to and from the Grid, while isolating the relatively flexible and delicate VCHP's from significant loads. Figure 2 shows a detail of this top mount connection to the Grid, which includes large cut-outs for access to electronics boxes mounted to the underside of the LAT.

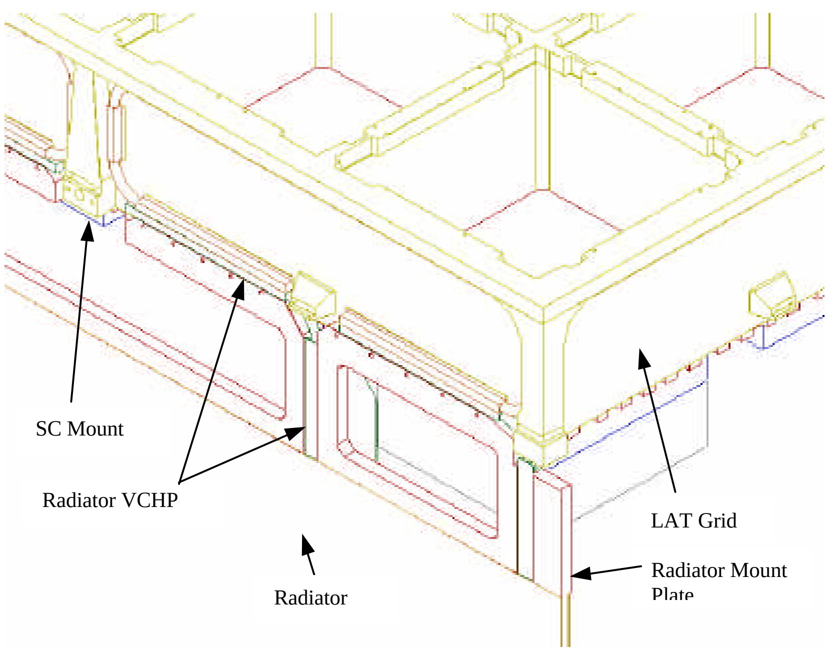

Figure 2: Detail of Radiator Mount to LAT Grid

The radiators are also tied to the spacecraft to provide additional support to the large, flat panels. The effect of the number and location of the support points on the behavior of the radiators was one of the issues investigated for this technical note. The support point locations affect the stiffness of the radiator panels, and how much, if any, auxiliary stiffening is needed.

3.1.3 Design Parameters

The radiator design and analysis parameters are shown in Table 1. These were used to generate the finite element models used in the analysis of various design options.

Parameter	Value	Comment
Width	1.6 m	
Height	1.8 m	
Ht of active radiator area	1.6 m	
Total active area	5.12 m^2	2 radiators x 2.56 m^2 each
Thickness	18 mm	total sandwich thickness
Core thickness	15 mm	alum honeycomb
Face sheets	1.5 mm	aluminum sheet
Z acceleration	6.6 g	max static-equivalent
X, Y acceleration	3.25 g	max static-equivalent

Table 1: Key Radiator Design and Analysis Parameters

The size of the radiators was set by the surface area needed for radiating the heat, and by the physical size available for them within the LAT stay-clear dimensions. Radiator static equivalient accelerations are the worst-case loads from the LAT/Spacecraft Interface Requirements Document (IRD). These were used to size the radiator mounts and supports.

3.1.4 Performance Assumptions

Two key driving parameters in the design of the radiators are the relative motion between the LAT and the spacecraft during launch, and the minimum natural frequency of a radiator panel.

Unfortunately, neither of these has been specified yet. Therefore, assumptions must be made for both of these requirements, based on the current understanding of the design.

First, regarding the relative motion between the LAT and spacecraft, we assume a maximum relative motion of +/- 2 mm in any direction. The 2 mm amplitude is derived from two sources. First, IRD section 3.2.2.8.1.1 states that the minimum lateral first-mode natural frequency of the Observatory is 12 Hz. To be conservative, we assume that all deflection associated with this mode is seen in the interface structure between the spacecraft and the LAT. Second, GEVS Table 2.4-4 shows that in the 20 Hz frequency range, the maximum expected magnitude of random vibration is 0.026 G^2/Hz. This corresponds to 0.56 g at 12 Hz.

Given a maximum expected acceleration of 0.56 g at 12 Hz, the expected peak amplitude of vibration would be slightly less than 1 mm. An amplitude of this magnitude assumes that all deflection occurs in the interface structure, and that the structure oscillates like a simple one degree-of-freedom system. Because this analysis is rudimentary, we doubled the deflection amplitude, giving ourselves the goal of being able to handle a relative motion of 2 mm between the spacecraft and LAT.

Second, we set the target minimum natural frequency of the radiator panels at 70 Hz. Large, flat panels like the radiators are susceptible to significant response from acoustic loads, so we tried to push for as large an out-of-plane natural frequency as possible, given a reasonable mass. This was the main criterion by which design options were optimized.

3.2 Radiator Analysis

3.2.1 Mounting Options Investigated

The radiator mount to the Grid must be rigid, to provide good heat transfer from the Grid and to carry the radiator structural loads. This rigid mount provides the primary structural support for the radiators, taking all launch loads in the plane of the radiators.

Given that the Grid mount is rigid, the radiator connection to the spacecraft must either be compliant, or the radiators themselves must be able to accommodate the potential 2 mm offset. At the outset, it was clear that the radiators have a high in-plane stiffness, so we looked exclusively at spacecraft supports which are compliant for relative motions parallel to the plane of the radiators. Assuming the radiators lie in planes which are parallel to the Observatory xz plane, this means that the radiator spacecraft supports must be compliant with respect to relative motion in the x and z directions. On the other hand, the radiators are not nearly as stiff out-of-plane. Thus, they may flex or bend out-of-plane to accommodate relative motions in the Y direction between the LAT and spacecraft. We investigated the loads imparted on the radiators due to such out-of-plane bending. Finally, we also looked at two- and four-point connections to the spacecraft. Supporting a radiator at two points with spars or flexures gives it the freedom to rotate freely out of plane, without imparting bending couples on the radiator. However, supporting such a large radiator at only two points means that there is a significant amount of unsupported flat area, which tends to lower the natural frequency. To raise the natural frequency, we added stiffening beams on the back side of the radiator.

3.2.2 Analysis Results

Figure 3 shows the mode shapes for the fundamental natural frequency of four of the design options we investigated. First, Figure 3a shows an un-stiffened radiator supported at two points, the location of which has been optimized to maximize natural frequency. The first-mode natural frequency (f_1) of this system is only 27 Hz, due completely to large-scale bowing of the entire panel. This clearly demonstrates the need for additional stiffening, or for additional support points.

Figure 3b shows the first-mode natural frequency of a four-point support, with two stiffening beams on the back side of the radiator. These beams are 3” x 1-3/4” x 1/8” wall aluminum rectangular structural tubing, with the support points located at the four ends of the beams. Analysis shows that f_1 = 74.1 Hz for this structure, with most of the large-scale panel bowing being suppressed by the two additional support points. The four-point support method significantly reduces the unsupported areas in the radiator.

The next logical step in stiffening the radiator is to completely eliminate the panel bowing by forming a box with the stiffening members. The resulting first mode shape (see Figure 3c) shows that deflection from this mode is dominated by the radiator edges “flapping” locally. For this configuration, f_1 = 92.4 Hz. The width and height of the box has been optimized to minimize the overall deflection, so the “flapping” of the vertical edges is balanced against the drumming of the radiator in the middle of the box.

While both of the previous designs produced stiff structures, they relied on four support points for this stiffness. Figure 3d shows the extension of the box concept to a two-point support. For this model, f_1 = 77.7 Hz, midway between the natural frequencies of the two four-point support designs. Here, stiffness is gained by extending the structural members up to near the Grid mount. This effectively eliminates the panel bowing mode, at the cost of increased structural mass. Analyses of

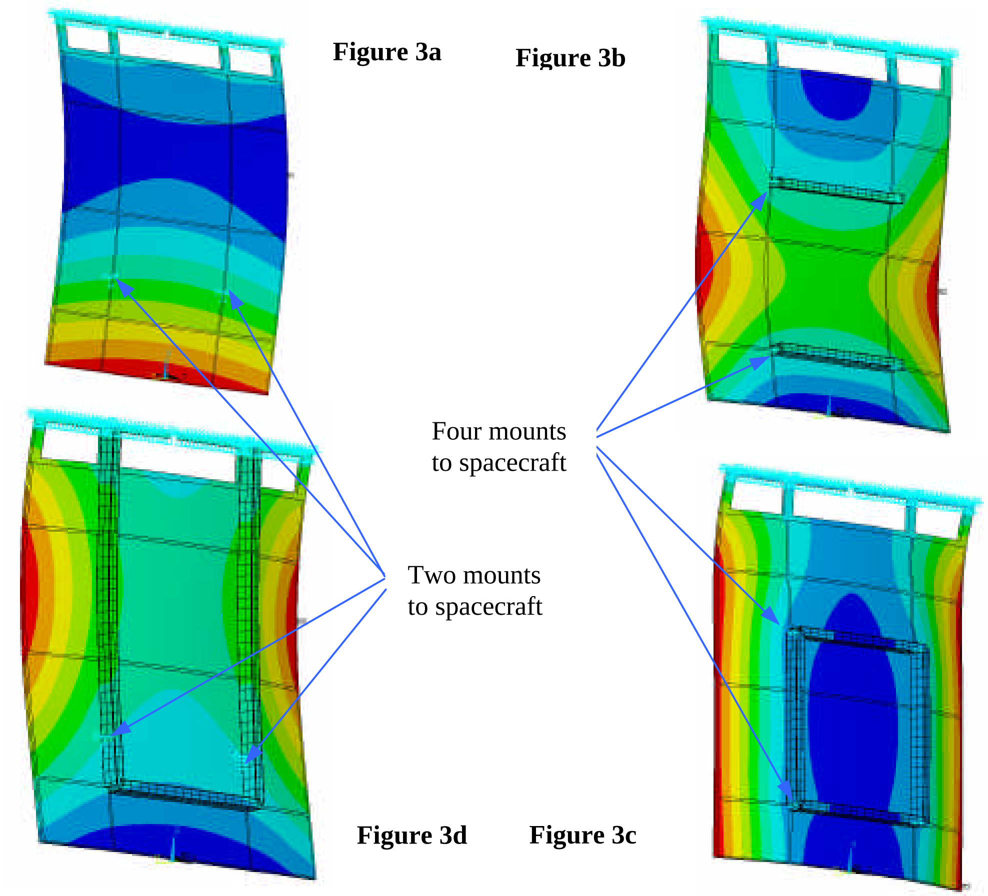

Figure 3: Mode Shapes of Four Radiator Options

models with shorter stiffening members shows that the natural frequency drops quickly as the end of the members get farther from the Grid.

A summary of the four supporting and stiffening options is shown in Table 2, along with their respective masses, excluding the mass of the supports.

Figure	**3a**	**3b**	**3c**	**3d**
Stiffener configuration	no beams	horizontal beams	window-frame	deep U
# Supports	2	4	4	2
Mass/Radiator (kg)	32.3	35.5	38.6	39.8
Nat Freq (Hz)	27.0	74.1	92.4	77.7

Table 2: Radiator Analysis Summary

Option 3a shows the baseline mass for an unstiffened radiator, so other options should be compared with it. Of the three stiffened designs, the two-point support design has the lowest stiffness to mass ratio, indicating that it is the least efficient design, structurally. However, it has definite advantages in a simpler interface to the spacecraft, and minimal out-of-plane loads imparted on the radiators.

3.3 Radiator Mount to Grid

The radiator is mounted to the Grid through an aluminum plate that is bonded to the top edge of the radiator. This plate is rigidly bolted to the Grid at four points, located next to the four VCHP's coming up from the radiator panel. For the vertical static-equivalent acceleration loading, the four points share the load equally. The heaviest radiator in Table 2 produces a reaction force of 650 N (150 lbf) at each of these four mount points, for the expected maximum acceleration of 6.6 g in the thrust direction.

For the case of lateral static-equivalent acceleration in the x direction, we assume that the reaction loads are taken only at the two extreme Grid mount points, while the center two mounts contribute nothing. Given this conservative assumption, the expected worst-case lateral acceleration of 3.25 g produces a reaction couple of 720 N (160 lbf) at the two mounts.

If the two maximum accelerations occur simultaneously, the worst-case mount reaction force is 1370 N (310 lbf). This is not a large load, and could be carried by a single pin, or a pattern of two or three bolts at each mount point.

For the four-point support design, an additional reaction force at the Grid arises from the out-of-plane distortion of the radiator due to the assumed 2 mm relative motion between the LAT and the spacecraft. Structural analysis of the radiator shows that the out-of-plane reaction force at the Grid mount due to this distortion is less than 130 N (30 lbf) at any of the four mount points. This is orthogonal to the in-plane reaction forces, and affects the pre-load needed on the bolts.

While a rigorous design of the radiator mount to the Grid was not in the scope of this analysis, the loads indicate that these mount points should be straightforward to design. Bolt loading is consistent with bolt sizes on the order of ¼" diameter or slightly larger.

3.4 Radiator Support from Spacecraft

The mounting concepts shown in Figure 3 all are based on a radiator spacecraft support design that allows unconstrained relative motion between the LAT and spacecraft, up to 2 mm. A strut or flexure type support will ensure that essentially no force is transmitted to or from the radiator in the x or z direction (parallel to the radiator plane). To first order, the only loads transmitted are along the strut axis, normal to the radiator plane.

For the two-point radiator connection to the spacecraft, these plane-normal reaction forces are solely the result of the transverse static-equivalent acceleration of 3.25 g, acting parallel to the y axis. This results in a reaction force of 420 N (94 lbf) at each of the two support points, which corresponds to 1/3 of the total acceleration load of the radiator carried by each support, with the remaining 1/3 carried by the Grid.

The four-point support concept has the advantage of splitting this reaction force four ways, so the greatest load is on the order of 300 N (67 lbf) at each upper (i.e. closest to the grid) support.

The out-of-plane bending of the radiator due to relative motion between the LAT and spacecraft produces another significant reaction force at the supports. Again, the greater load is on the two supports closest to the Grid, where the expected reaction force is 253 N (57 lbf) on each, for the window-frame stiffener design. The combined support load is 553 N (124 lbf) for the four-point support.

In conclusion, the spacecraft support reaction force for the four-point design is actually greater than that of the two-point design, due largely to the out-of-plane bending of the radiator. While the forces are not large, they are on the order of the weight of the radiator, and would need to be accounted for in the structural design of the radiators themselves.

3.5 Proposed Design

3.5.1 Baseline Design

Our analysis has produced a rough conceptual design for the LAT radiators. It has shown that such a large panel can be designed to have a relatively high natural frequency, even with only a mount at the Grid and two supports on the spacecraft. Furthermore, the analysis has shown that either a two- or four-point connection to the spacecraft is plausible, depending on the actual design of the spacecraft.

Our proposed baseline design incorporates the two-point spacecraft support (see Figure 4). There are three reasons for this, none of which are especially compelling. First, the two-point support provides a cleaner interface to the spacecraft. Obviously, there are only two points to deal with, but

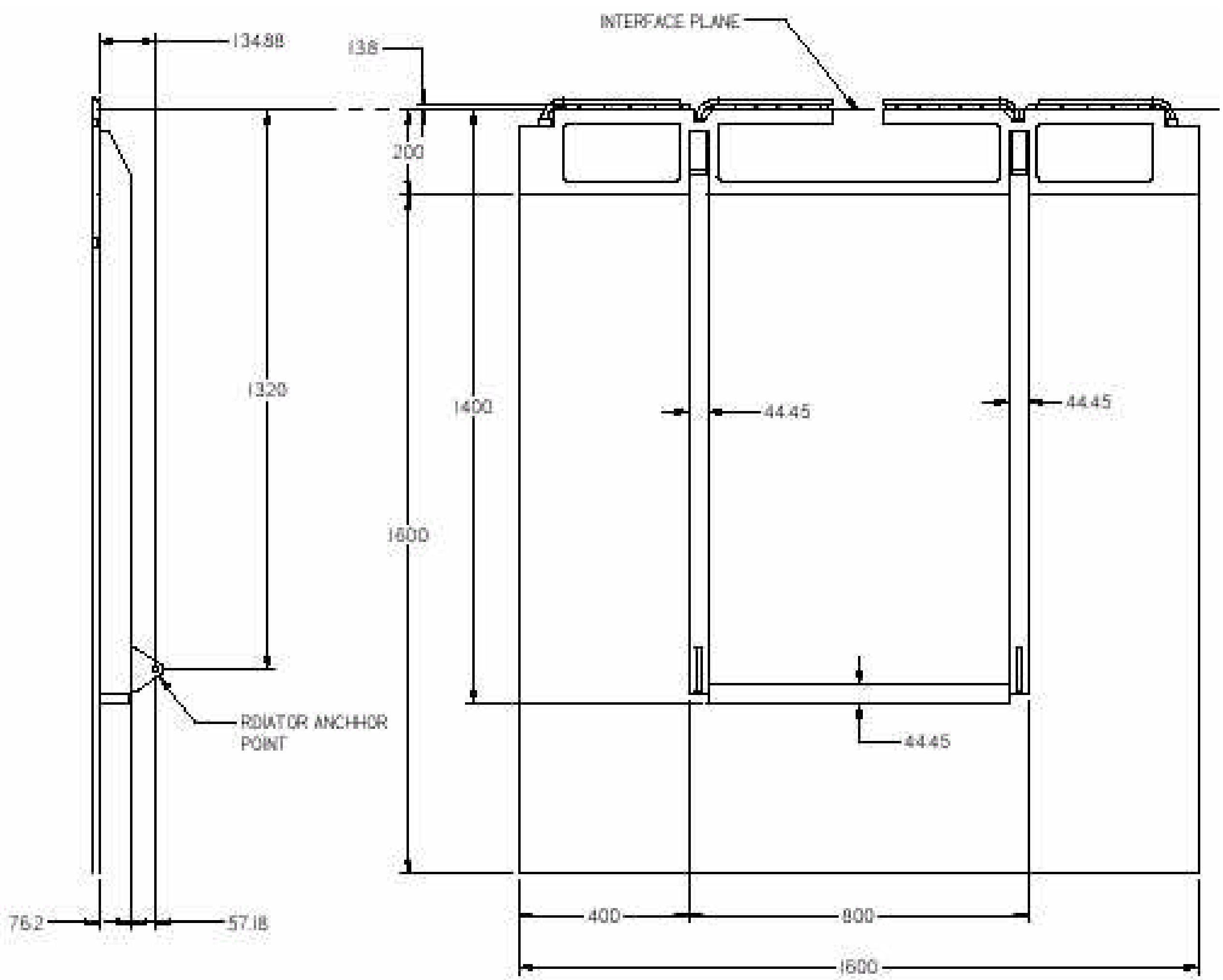

Figure 4: Radiator Design Layout (mm)

it also decouples the support point location and relative motion issues from the radiator design. A four-point support imparts loads on the radiator which are dependent on both of these variables.

Second, the loads on the radiator from a two-point support are less than for a four-point design. This should simplify the details of the radiator sandwich panel inserts. Finally, the two-point support requires fewer parts, less integration time, and more flexibility during integration.

On the negative side, the two-point support concept requires more stiffening members, which add to the total mass. However, this extra mass is partially offset by the weight savings because there are only two supports instead of four.

While none of these reasons is compelling, they lead us to the conclusion that the two-point support is preferable.

3.5.2 Location of Two-Point Mount

The exact location of the spacecraft supports cannot be determined until the spacecraft design is better understood. However, Figure 5 shows how variations in this support location affects the natural frequency of the radiator. The graph suggests that the support should be kept within +/- 60 mm of the optimal location shown of 1320 below the interface plane, so the radiator first mode frequency stays above 75 Hz.

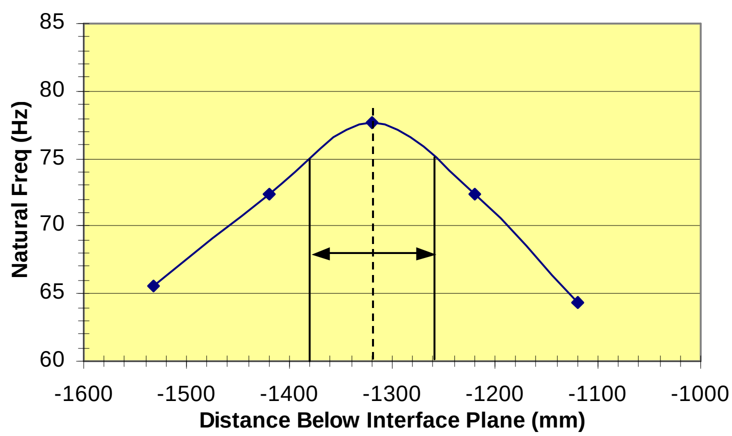

Figure 5: Effect of Support Location on Natural Frequency

3.5.3 Provision for Spacecraft Solar Arrays

The radiator design concept discussed in this note, and shown in Figure 4, is designed to be mounted on the spacecraft +y and –y faces. These are also the sides where the spacecraft solar arrays will be mounted. This mounting will require modifications to the basic design concept, by one of three possible methods.

First, a hole could be put in the radiator panel, through which the mast of the solar array would extend. This approach most likely minimizes the reduction in radiator area, but would tightly couple the integration and any servicing of the two components. For example, access to the bearing or motor at the base of the solar array shaft would likely require that the radiator is removed. However, this would require that the solar arrays are first removed, something which does not seem preferred.

The second approach to solve this Gordian note problem is to split the radiator panel in half. Thus, either radiator panel could be removed without disturbing the solar arrays. However, the structural support and thermal design of the radiators becomes significantly more complex, making this an undesirable option.

Finally, the radiator panel could be notched at the bottom. This allows the radiator to be removed without disturbing the solar array, and should allow for access to the base of the array support shaft, even with the radiator already integrated. The most significant implication of this design is that it forces the solar arrays to be mounted low on the spacecraft, to minimize the depth of the notch in the radiator.

We propose that the notched radiator design should be the baseline for design studies of the spacecraft and radiators.